Development of a Nonlinear Internal Wave Tactical Decision Aid

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LONG-TERM GOALS

The long term goal of the project is to develop a prediction methodology for the occurrence of nonlinear internal waves that can be used as the basis for a future Tactical Decision Aid.

OBJECTIVES

The principal objective is to establish a procedure and identify a set of parameters and values that can serve as the basis for the prediction of nonlinear internal wave occurrences in the South China Sea.

APPROACH

The effort is using tidal and environmental parameters derived through satellite imagery and in situ observations in combination with model data. The work is being done in coordination with Dr. Lou St. Laurent of Florida State University. The initial work is dedicated to the northern portion of the South China Sea between the Luzon Strait and the Chinese coast near Honk Kong, but the approach is applicable any wave occurrences. The South China Sea effort has been relying on satellite imagery collected since April 2003 and in situ data collected since April 2005. Satellite data to support the work include wind speed and direction, sea surface temperature, MODIS (Moderate Resolution Imaging Spectroradiometer) and synthetic aperture radar (SAR) imagery. In situ measurements come from 2005 WISE/VANS experiments and data collected as part of the Non-Linear Internal Wave Initiative (NLIWI) program. The TPXO6 Tidal Model from Oregon State University is being used for tidal height and current prediction.

WORK COMPLETED

A preliminary prediction scheme has been developed and being applied to the solitons originating in the Luzon Strait and propagating across South China Sea. It is based on creating a phase speed vs. depth profile that can be mapped to all points in the basin. The prediction model has four “free” parameters

- Wave Phase Speed (C0) - Determines wave locations and spacing in the deep basin.
- Multiplier (B) - Determines wave refraction and spacing near the shelf.
- Wave Origin Latitude - Determines wave front shape.
- Wave Origin Longitude - Determines wave front radius of curvature and tidal generation phase.

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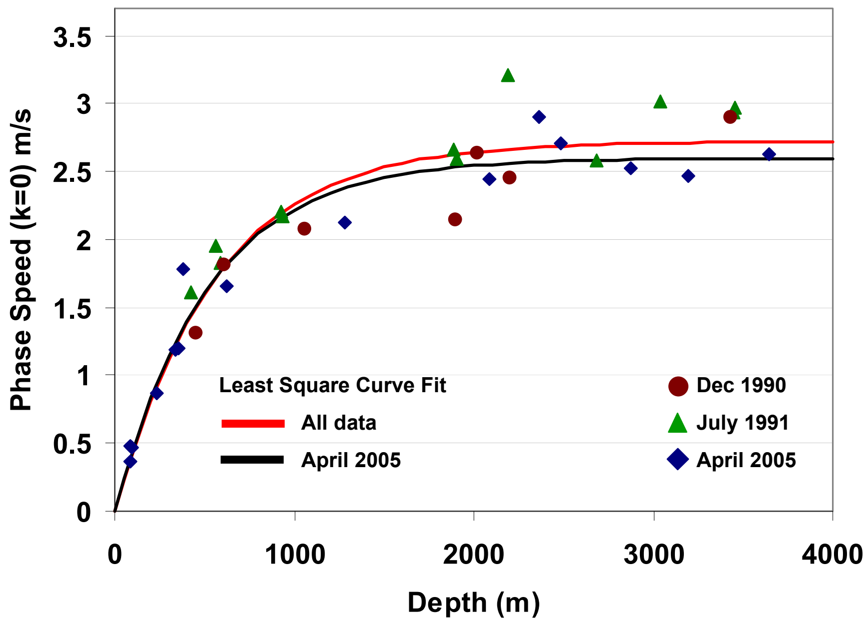

Figure 1. Internal wave phase speed vs. depth derived from CTD data collected during December 1990, July 1991 and April 2005. The phase speeds increase from near 0.5 m/s at 100 meters depth to approximately 2.6 m/s at depths greater than 2000 meters

The initial phase speed vs. depth profile was created by solving the Taylor-Goldstein equation for linear internal waves. The calculations use N(z) (Brunt-Väisälä frequency) values derived from in situ conductivity, temperature and depth (CTD) measurements (Figure 1). A smooth function to represent the relationship between speed and depth is constructed using parameters C0 and B. Model parameters C0, B, and Wave Origin Latitude and Longitude are found by minimizing the residuals between the internal wave locations in the MODIS and SAR imagery and the wave locations predicted by the model. Once a particular C0, B, and wave origin are selected and the travel time of the observed internal waves are calculated the tidal values at the time of generation can be found. By processing a large number of images, over a variety of time periods, seasonal (or monthly) values ranges will be found (with the expectation the wave origins will be consistent for a particular time period).

RESULTS

Figure 2 shows a composite MODIS visible wavelength image and an ERS-2 SAR image acquired on 22 August 2005 at 02:50 and 02:45 UTC respectively. Wavefronts A,B,and C represent internal waves that were generated on consecutive days∗. Running the positions of these wavefronts, and the arrival times of the waves at PIES mooring P1, through the fitting process, gives model parameters C0=3.13 m/s, B=542.17 and a wave origin at 20.43oN and 121.50oE. These parameters correspond to a wave generation time of approximately 0.85 hours after the E/W component of current goes to zero (slack tide) and 2.3 hours before the maximum westward flow (Figure 3).

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*Figure 2 also shows a wave front between B and C with different characteristics than A, B and C. These "Semi-diurnal" waves have been noted in other data from the late summer / early fall and vary in their spacing position between the wave groups generated before and after them. This suggests either a second wave generation location or generation at a different phase in the tidal cycle. The wave front is not distinctive enough to back project uniquely.

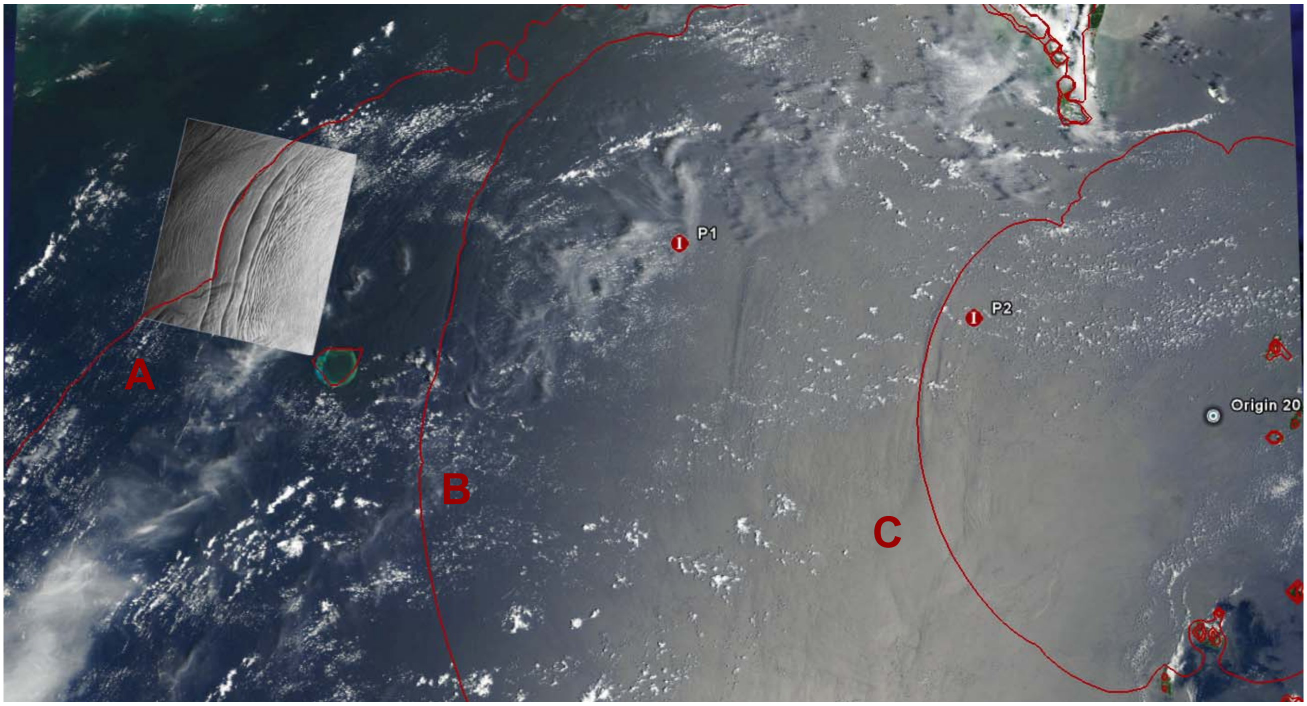

Figure 2. Combined MODIS visible and ERS-2 SAR image of the South China Sea acquired 22 August 2005 at 2:50/2:45 UTC. The image shows three internal wave packets generated on consecutive days along with the model contours. Curves for A, B and C positions are at 2.66, 1.64 and 0.61 days after generation. P1 and P2 are the PIES mooring locations.

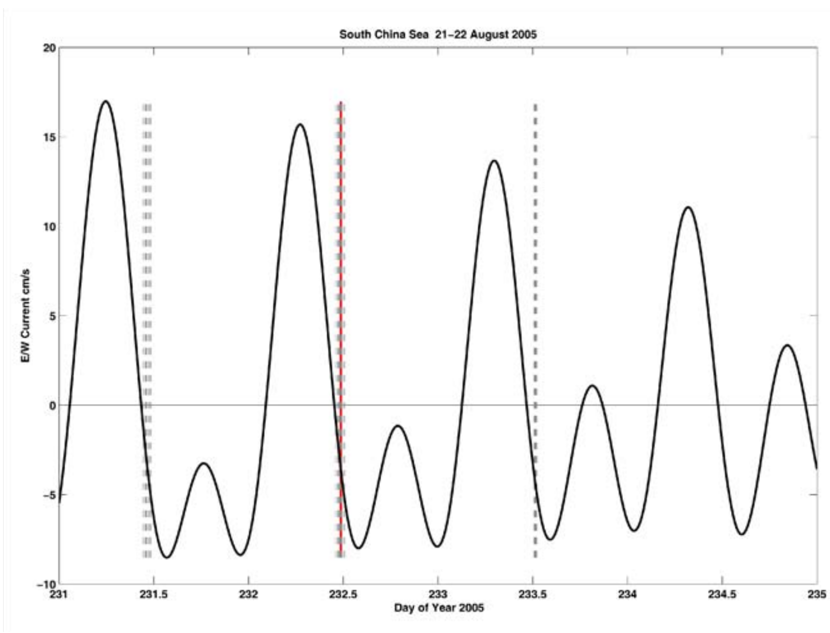

Figure 3. East/West current at 20.4oN, 121.5oE from the TPX06 tidal model during the days prior to the acquisition of the MODIS image shown in Figure 2. Back projection of the wavefronts shown in Figure 2 place internal wave generation at approximately 0.85 hours after slack tide.

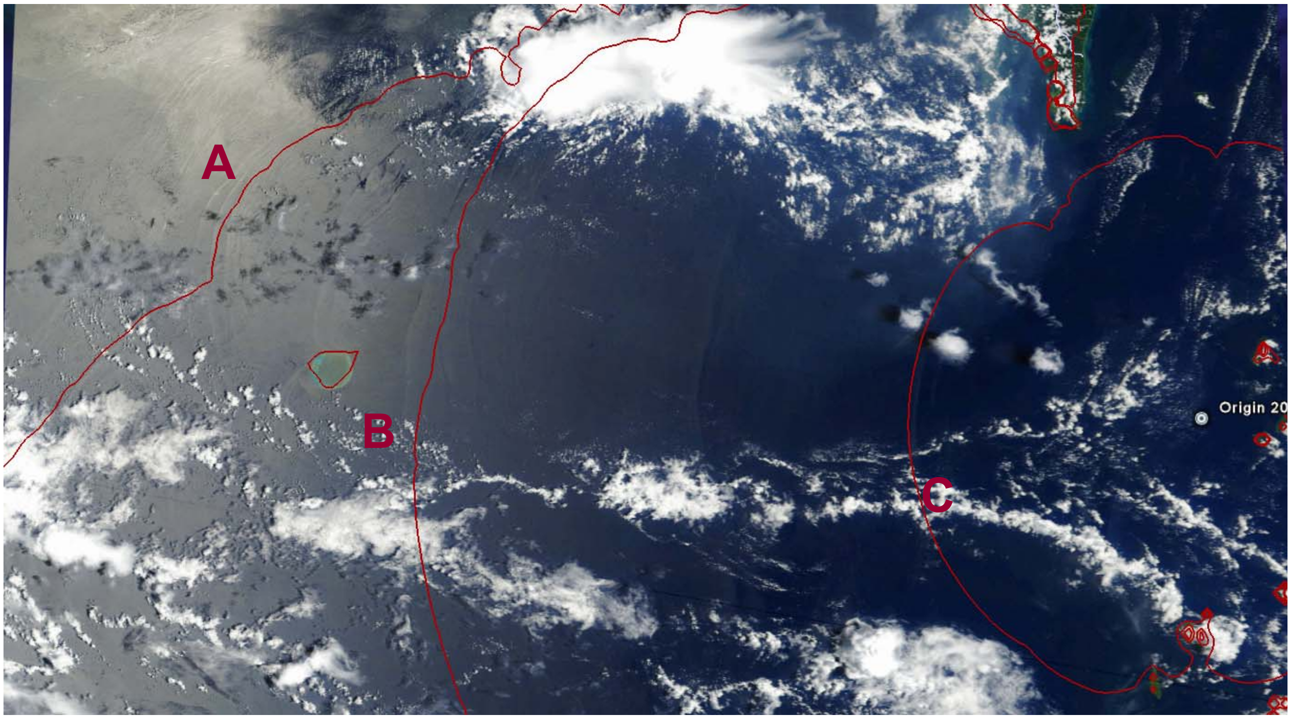

Figure 4. MODIS visible image of the South China Sea acquired 14 August 2006 at 3:05 UTC. The image shows predicted internal wave positions calculated from the model parameters derived from the 22 August 2005 image (Figure 2).

Figure 4 shows the results of applying the model parameters derived from the 22 August 2005 imagery to a MODIS image acquired on 14 August 2006. The model shows good agreement with the shapes and spacing of the three wavefronts. The wavefront B is by approximately 15 km (1 hour) ahead of the image location. Wavefront A is also approximately 15 km ahead of the prediction but this corresponds to approximately 1.5 hours due to the slower propagation speeds on the shelf.

Table 1. The results of fitting the C0, B and Origin parameters to 4 imagery collections.

	Best Fit Parameters				**STD (days)**	**Best Fit with origin at 20.35 121.5**		**STD (days)**
	Lat	**Lon**	**C0**	**B**		**C0**	**B**	
21-22 Aug 2005	20.4	121.5	3.1	542.0	0.010	3.2	554.1	0.011
2-4 July 2005	20.3	121.7	2.4	312.4	0.046	2.5	337.5	0.042
22-26 June 2006	19.8	122.4	2.9	452.0	0.035	2.8	448.1	0.040
13-14 July 2003	20.3	121.1	3.0	426.2	0.041	3.0	422.6	0.042

Table 1 shows the results of fitting the model parameters to imagery collected during June, July and August. Fitting was done both over the 4-D model space and for a fix origin. The origin for these cases is considered as a “point source” and may not be the physical origin of the waves. Data from additional months is being processed to determine the parameters for other monthly stratifications.

IMPACT/APPLICATIONS

The investigation for the South China Sea will have established a procedure for determining the environmental and/or tidal parameters associated with wave generation. By knowing the time and location of internal wave generation along with a time travel map for a region, it is then possible to establish a predictive capability for time and location of an internal wave front over the region of interest. The procedure can be applied to other locations of interest and serve as the basis of an internal wave tactical decision aid.

RELATED PROJECTS

The PI is the author of the 2nd Edition of the *Atlas of Internal Solitary like Waves and Their Properties* (March 2004). The purpose of the Atlas is to document the various locations and manifestations of internal waves around the world. The Atlas contains 54 case studies of wave occurrences (approximately 550 pages). A copy of the Atlas is maintained on the web at www.internalwaveatlas.com and CD copies are also readily available.